The Repetition of Seasonal Variations in the Tropospheric Zenith Range Effect

K. L. Thuleen and V. J. Ondrasik
Tracking and Orbit Determination Section

Using radiosonde balloon data taken from sites close to the DSN tracking stations, the tropospheric zenith range effect $\Delta\rho_z$ has been computed throughout 1967 and 1968. The behavior of $\Delta\rho_z$ has definite seasonal trends which are similar in both years. With the modification of the tropospheric model, which is used to calibrate radio tracking data to include these seasonal trends, the navigational errors, produced by inaccuracies in representing the zenith range effect, may possibly be reduced by as much as 40%.

I. Introduction

One of the error sources which corrupts range and doppler data, and thereby degrades navigational capabilities, is the troposphere. To determine the amount of this tropospheric-induced degradation, and also to improve the tropospheric model used for calibrations, it is very valuable to examine the temporal behavior of the tropospheric zenith range effect $\Delta\rho_z$. A study of the 1967 behavior of $\Delta\rho_z$ was reported in Ref. 1 and led to the following tentative conclusions:

(1) $\Delta\rho_z$ is composed of a dry portion $\Delta\rho_z(d)$ and a wet portion $\Delta\rho_z(w)$.

(2) The dry portion is approximately 90% of $\Delta\rho_z$ and is very highly correlated with the surface pressure.

(3) Most of the variations in $\Delta\rho_z$ are due to the wet portion which often has little correlation with surface quantities.

(4) Assuming that the wet portion stays constant at its yearly average can lead to equivalent station location errors of 0.4 m (for a minimum elevation angle of 10 deg).

(5) The wet portion of the tropospheric zenith range effect appears to have definite seasonal trends.

It was also mentioned in Ref. 1 that if the apparent seasonal trends in $\Delta\rho_z(w)$ are repeatable from year to year, it should be possible to improve the troposphere model which is used to calibrate the tracking data, and thereby reduce the tropospheric-induced navigational errors. The primary purpose of this article is to show that the seasonal behavior of $\Delta\rho_z(w)$ was very similar in the years 1967 and 1968. If it can be established that this similarity continues for a few years, it may be valuable to include historical data in the tropospheric calibration model.[2]

Since $\Delta\rho_z(d)$ can be computed from surface pressure measurement, emphasis will be placed upon results involv-

[2]Such modifications have recently been made to the operational software supporting the *Mariner* Mars 1971 mission.

ing $\Delta\rho_z(w)$, although results will occasionally be given for $\Delta\rho_z(d)$.

The navigational errors produced by the variation of the zenith range effect should not be taken to represent the total effect of the troposphere. Unfortunately, there are other possible tropospheric error sources which may contribute significantly to the errors produced by the troposphere. Three such error sources arise from (1) translating $\Delta\rho_z$, computed from radiosonde balloon data, to the tracking station, (2) mapping zenith values to arbitrary elevation angles, and (3) effects produced by the inhomogeneous structure of the troposphere. These other tropospheric error sources are currently under investigation. In particular, the Chao article[1] in this volume reports on the range errors produced by mapping the zenith range effect down to arbitrary elevation angles with an incorrect refractivity profile.

II. Zenith Range Effect

As shown in Ref. 1, $\Delta\rho_z$, $\Delta\rho_z(d)$, and $\Delta\rho_z(w)$ may be computed from the following integral:

$$\Delta\rho_z = \Delta\rho_z(d) + \Delta\rho_z(w) = \int_0^\infty [N_d(h) + N_w(h)]\, dh$$

where

$N = (n - 1) \times 10^6$

n = index of refraction

h = altitude above surface

The dry and wet refractivities, N_d and N_w, may be calculated as a function of altitude by using data gathered by radiosonde balloons.

With the help of Mr. Richard Davis and Mr. Larry Snelson of the National Climatic Center in Asheville, North Carolina, radiosonde balloon data from the sites listed in Table 1 was obtained for the years 1967 and 1968.

By the methods described in Ref. 1, this data was converted into refractivity profiles and integrated to yield $\Delta\rho_z$, $\Delta\rho_z(d)$, and $\Delta\rho_z(w)$. Unfortunately, much of the data only went up to approximately 6.10 km (20,000 ft)[2] and it was necessary to terminate the integration at the terminal integration height of 4.57 and 6.10 km (15,000 and 20,000 ft) for the overseas and Yucca Flats stations, respectively. This is not a serious limitation because most of variability occurs within this region. Figure 1 shows the behavior of the wet portion of the tropospheric zenith range error during 1967 and 1968 above the radiosonde balloon sites listed in Table 1. From these figures it is clear that behavior of $\Delta\rho_z(w)$ during 1967 and 1968 was very similar. A clearer comparison between the two years may be obtained by averaging the total, dry, and wet tropospheric zenith range effects for each month. These monthly averages $\Delta\bar{\rho}_z$, $\Delta\bar{\rho}_z(d)$, and $\Delta\bar{\rho}_z(w)$ are shown in Figs. 2–6, along with the associated standard deviations and maximum and minimum values. In order that these averages be representative of the zenith range effect due to the entire troposphere, and not just the first 4.57 or 6.10 km (15,000 or 20,000 ft), dry and wet refractivity models have been employed to supplement the radiosonde balloon data. The dry model computes the contribution to $\Delta\rho_z(d)$ above the terminal integration height by the equation given on page 32 of Ref. 1 and gives a very accurate (1%) value. The wet model assumes a refractivity profile above the terminal integration height, which starts with the monthly average refractivity at this height and decreases linearly to zero at 9.14 km (30,000 ft). Refractivity profiles which have been averaged over a month have been computed by C. C. Chao (see Footnote 1). An example of such an average profile, and the wet model which has been used to supplement the integrated monthly average of $\Delta\rho_z(w)$, is shown in Fig. 7. The supplementary portions of the averaged $\Delta\rho_z(w)$ are shown in Figs. 2–6.

To facilitate the comparison of the 1967 and 1968 averaged zenith range effects, these averages have been overlayed in Fig. 8. From this set of figures, it is easily seen that the behavior of the tropospheric zenith range effects are very similar during 1967 and 1968.

III. Apparent Changes in Station Locations Produced by the Troposphere

A useful artifice for investigating navigational errors, such as the ones produced by the troposphere, is to describe them in terms of equivalent errors in tracking station locations. As described in Ref. 2, an effect which corrupts tracking data can be decomposed into parameters, one of which is the apparent change in the station's distance off the Earth spin axis, Δr_s, and another is the apparent change in the station's longitude, $\Delta\lambda$. These errors in equivalent station locations can be translated very easily into declination and right ascension by the method given in the above reference.

[1]Chao, C. C., "New Tropospheric Range Corrections With Seasonal Adjustment" (this volume).

[2]Values in customary units are included in parentheses after values in SI (International System) units if the customary units were used in the measurement or calculations.

Once the tropospheric-induced range error, $\Delta\rho$, has been specified as a function of elevation angle, the equivalent station location errors can be computed by the method described in Ref. 1. To obtain some feeling of the superiority of a tropospheric model which includes the seasonal variations in $\Delta\rho_z(w)$, equivalent station location errors will be computed for each month, from the following tropospheric range errors:

$$\Delta\rho = \frac{\delta\rho_z(w,i)}{\sin\gamma}, \qquad i = 1,2$$

where

γ = elevation angle

$\delta\bar{\rho}_z(w,1) = \Delta\bar{\rho}_z(w,1968)$ − yearly average of $\Delta\rho_z(w,1967)$

$\delta\bar{\rho}_z(w,2) = \Delta\bar{\rho}_z(w,1968) - \Delta\bar{\rho}_z(w,1967)$

The first model which uses $\delta\bar{\rho}_z(w,1)$ will give monthly errors that result from calibrating the 1968 data with a model which assumes $\Delta\rho_z(w)$ is constant and has a value equal to the 1967 yearly average of $\Delta\rho_z(w)$. The second model which uses $\delta\bar{\rho}_z(w,2)$ will give monthly errors that result from calibrating the 1968 data with a model which assumes $\delta\rho_z(w)$ is constant for a month, but changes to the 1967 value of $\Delta\bar{\rho}_z(w)$ from month to month. Figure 9 gives the monthly averages of apparent change in r_s, $\Delta\bar{r}_s$, for each of these models using $\delta\bar{\rho}_z(w)$ values taken from the radiosonde balloon sites closest to Goldstone and Madrid, as given in Figs. 8a and 8b. The values of $\Delta\bar{r}_s$ are computed for each station viewing a zero declination satellite during a symmetric tracking pass with minimum elevation angles of 10 deg. Since both $\Delta\rho$ and the tracking pass are assumed to be symmetric, $\Delta\lambda = 0$. Table 2 contains the yearly average of $|\Delta r_s|$ for the two models and two stations. From Fig. 9 and Table 2, it is easily seen that the inclusion of the seasonal variations of $\Delta\rho_z(w)$ in the model describing the tropospheric zenith range effect typically reduces the troposphere-induced equivalent station location errors by 25 or 40%.

IV. Summary and Conclusions

Using 1967 and 1968 radiosonde balloon data taken from sites close to the DSN tracking stations, values of the total, dry, and wet tropospheric zenith range effects were calculated. The behavior of $\Delta\rho_z(w)$ has definite seasonal trends which were very similar for each year. The effects on radio tracking data of modeling the 1968 $\Delta\rho_z(w)$ by assuming it to be constant, with a value equal to the 1967 yearly average, can grossly be represented by an equivalent station location error of $\Delta r_s = 0.3$ m for a minimum elevation angle of 10 deg. If the model of $\Delta\rho_z(w)$ includes historical data regarding the seasonal trends of $\Delta\rho_z(w)$, the equivalent station location errors may be reduced by 25–40%.

Clearly any conclusions which may be reached from an examination of the 1967 and 1968 data suffer from the fact that only two years of data have been investigated. Before a great deal of confidence may be given to these conclusions, several more years of data should be examined.

References

1. Ondrasik, V. J., and Thuleen, K. L., "Variations in the Zenith Tropospheric Range Effect Computed From Radiosonde Balloon Data," in *The Deep Space Network*, Space Programs Summary 37-65, Vol. II, pp. 25–35. Jet Propulsion Laboratory, Pasadena, Calif., Sept. 30, 1970.

2. Mulhall, B. D., "Evaluation of the Charged Particle Calibration to Doppler Data by the Hamilton–Melbourne Filter," in *The Deep Space Network*, Space Programs Summary 37-57, Vol. II, pp. 24–29. Jet Propulsion Laboratory, Pasadena, Calif., May 31, 1969.

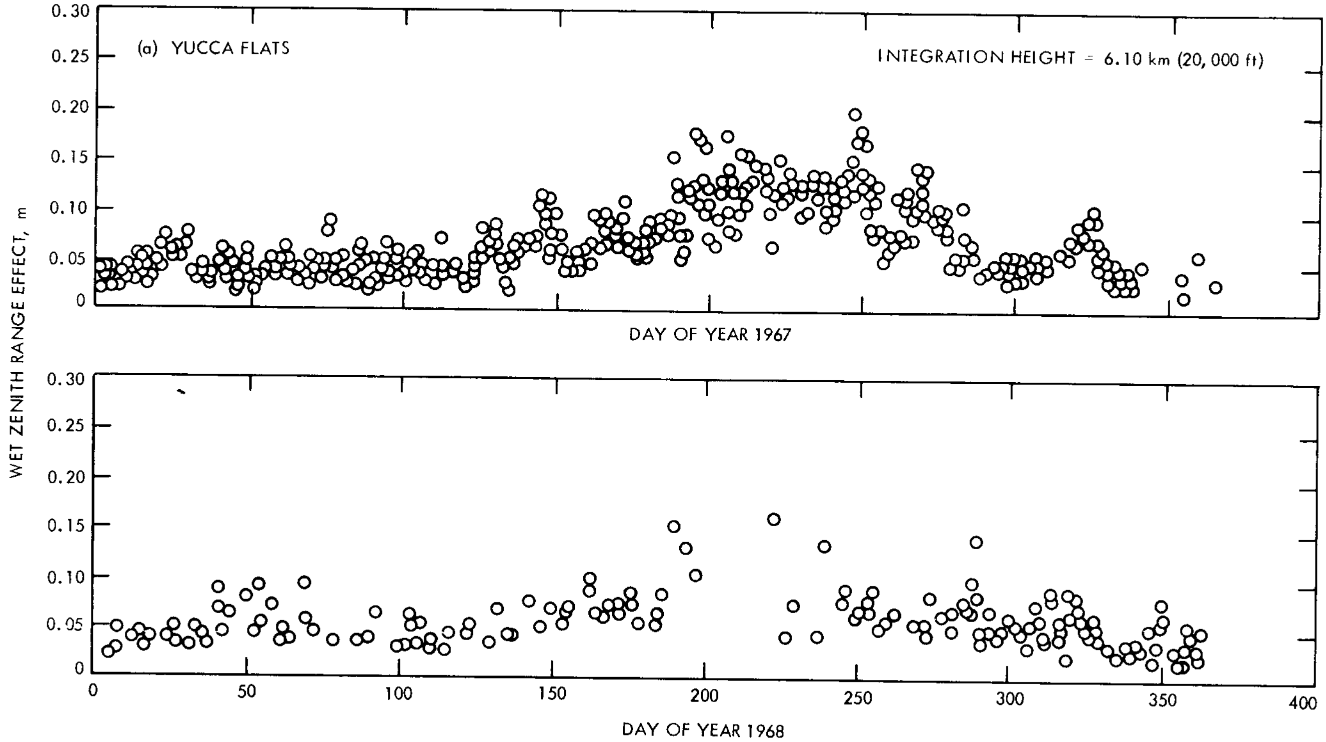
Table 1. Radiosonde balloon site parameters

Radiosonde station	Latitude	Longitude	Elevation, m	Nearest DSS	DSS elevation, m	Distance from DSS, km
Yucca Flats	36°57′ N	116°5′ W	724	Goldstone[a]	1190	200
Madrid	40°28′ N	3°34′ W	606	Madrid[b]	789	70
Wagga	35°10′ S	147°28′ E	214	Canberra	656	140
Woomera	31°9′ S	136°48′ E	165	Woomera	151	12
Pretoria	25°44′ S	28°11′ E	1330	Johannesburg	1398	50

[a]DSS 14.
[b]DSS 61.

Table 2. Equivalent station location errors for a constant and variable model of $\Delta\rho_z(w)$

Model	Constant for	Assumed $\Delta\rho_z$	$\Delta\bar{r}_s$ (Goldstone)	$\Delta\bar{r}_s$ (Madrid)
1	1 yr	1967 yearly avg of $\Delta\rho_z$	0.19 m	0.26 m
2	1 mo	1967 monthly avg of $\Delta\rho_z$	0.14 m	0.15 m



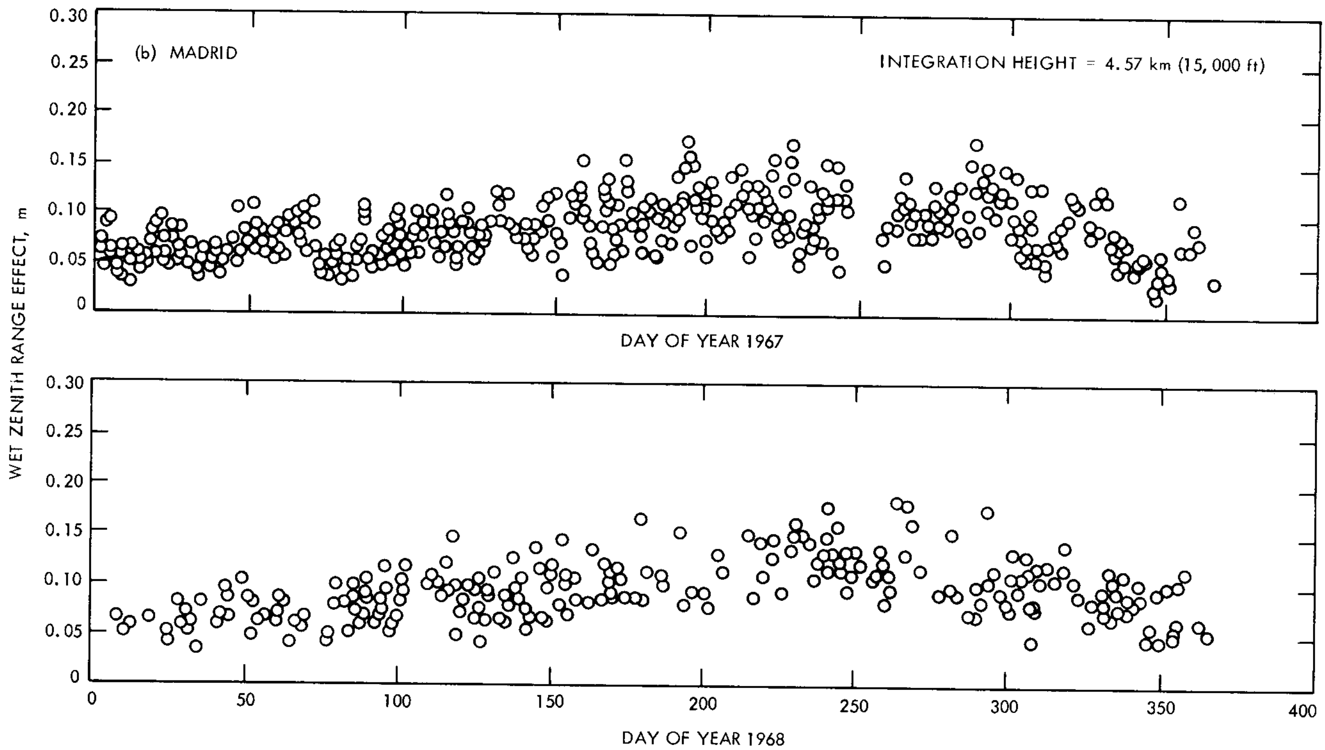
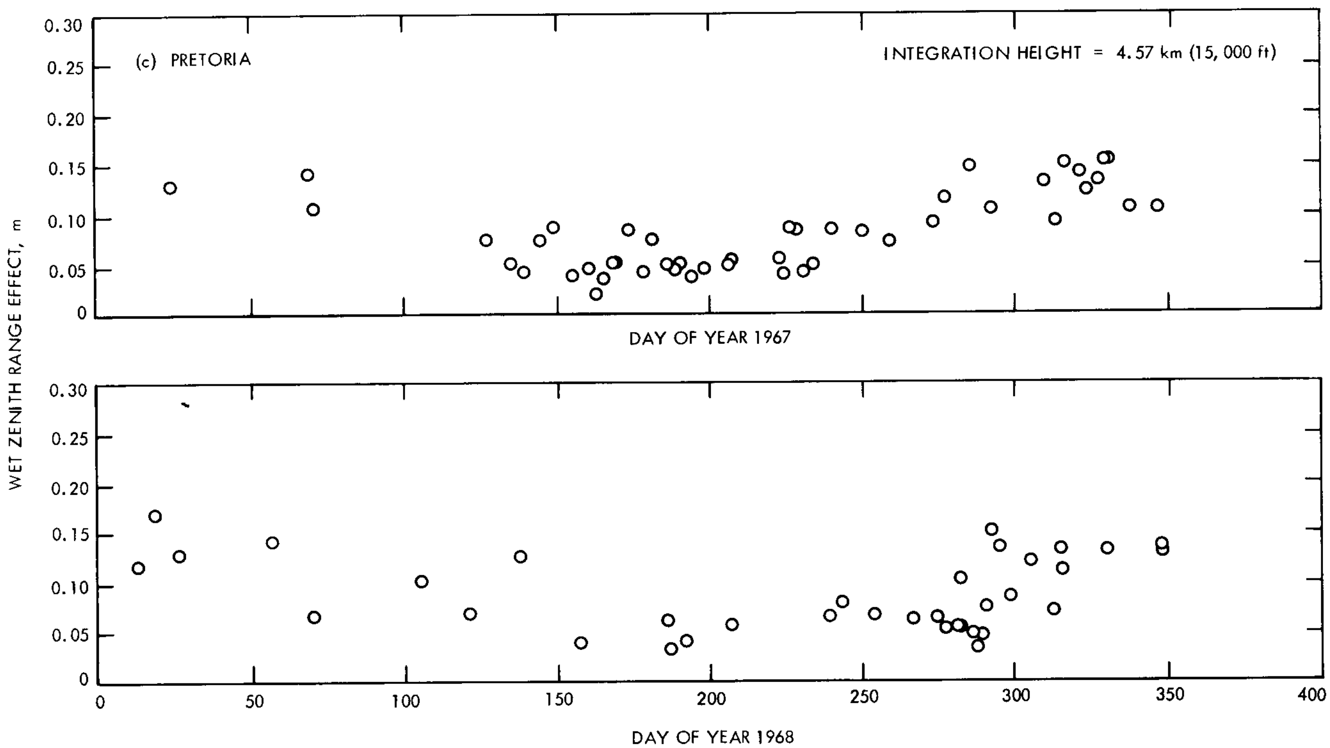


Fig. 1. Wet zenith range effects over various sites during 1967 and 1968


(c) PRETORIA
INTEGRATION HEIGHT = 4.57 km (15,000 ft)
WET ZENITH RANGE EFFECT, m
DAY OF YEAR 1967
DAY OF YEAR 1968
0.30
0.25
0.20
0.15
0.10
0.05
0
0
50
100
150
200
250
300
350
400

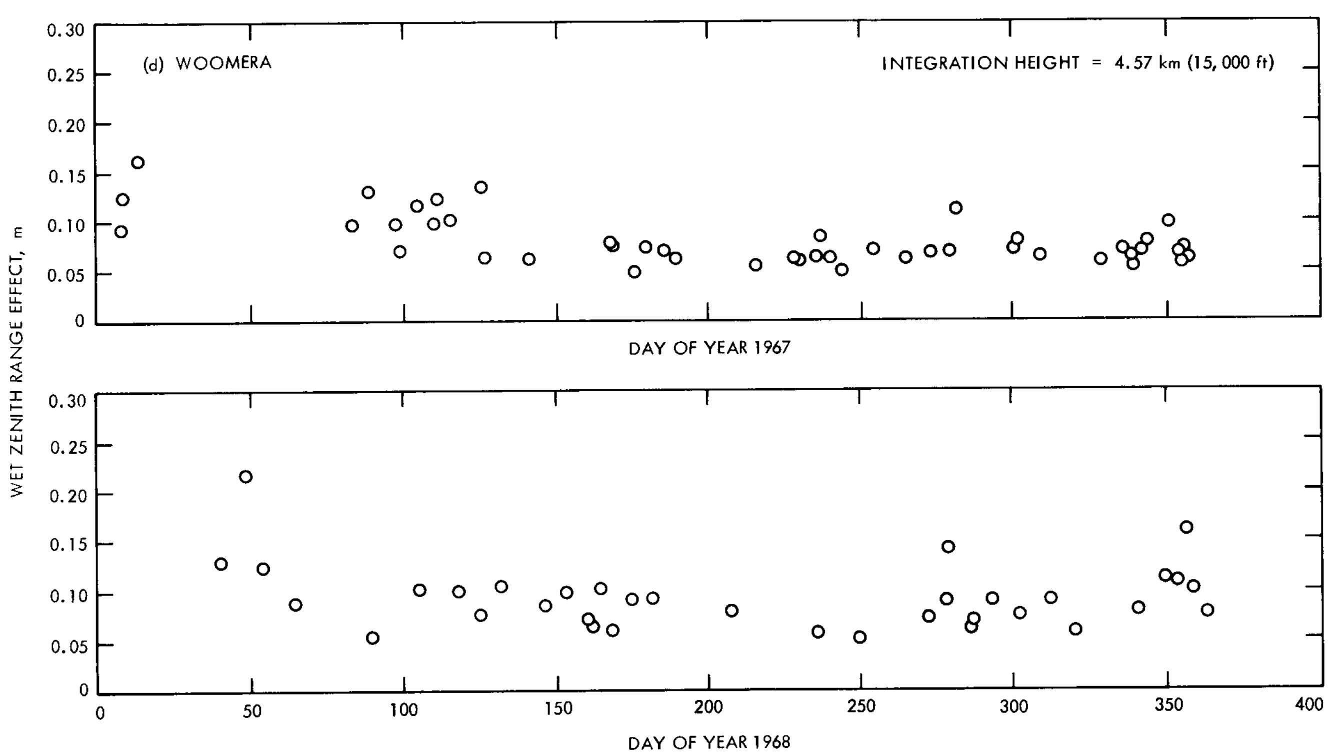
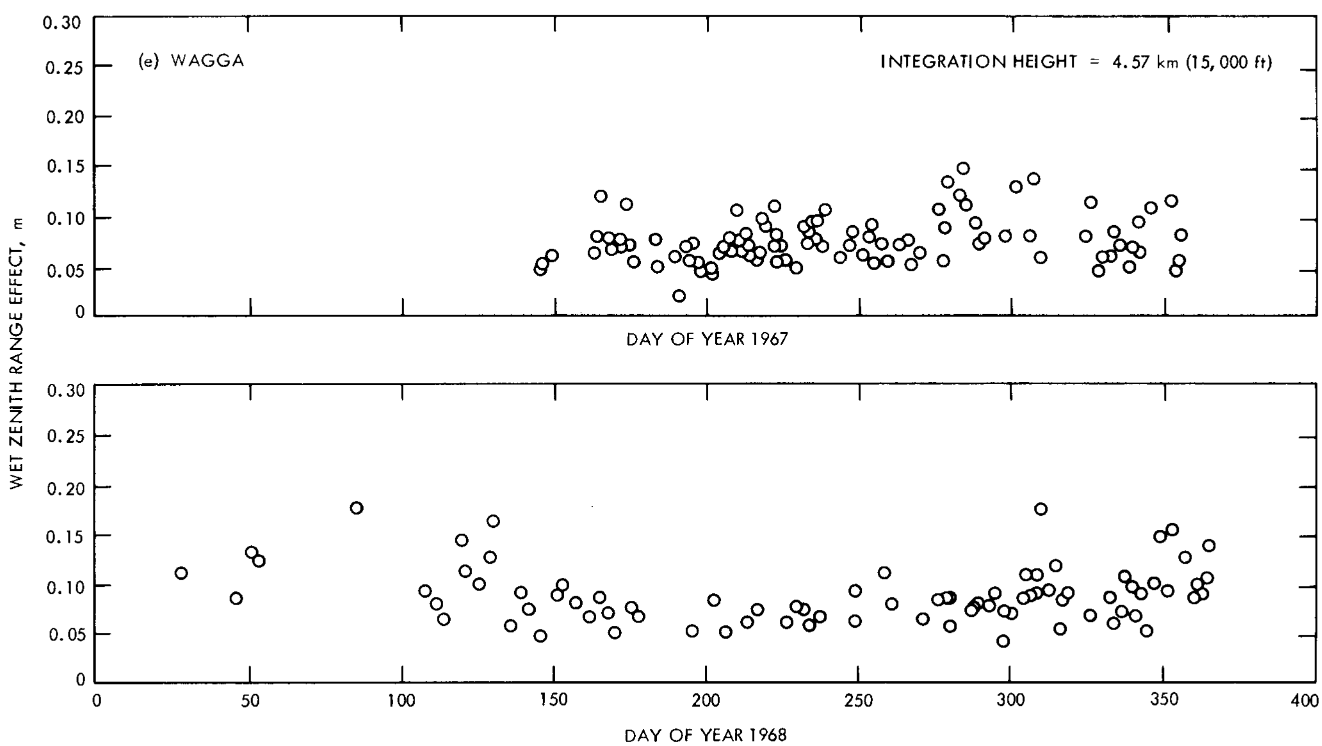

(d) WOOMERA
INTEGRATION HEIGHT = 4.57 km (15,000 ft)
WET ZENITH RANGE EFFECT, m
DAY OF YEAR 1967
DAY OF YEAR 1968
0.30
0.25
0.20
0.15
0.10
0.05
0
0
50
100
150
200
250
300
350
400

Fig. 1 (contd)



0.30
0.25
0.20
0.15
0.10
0.05
0
(e) WAGGA
INTEGRATION HEIGHT = 4.57 km (15,000 ft)
DAY OF YEAR 1967
WET ZENITH RANGE EFFECT, m
0
50
100
150
200
250
300
350
400
DAY OF YEAR 1968

Fig. 1 (contd)

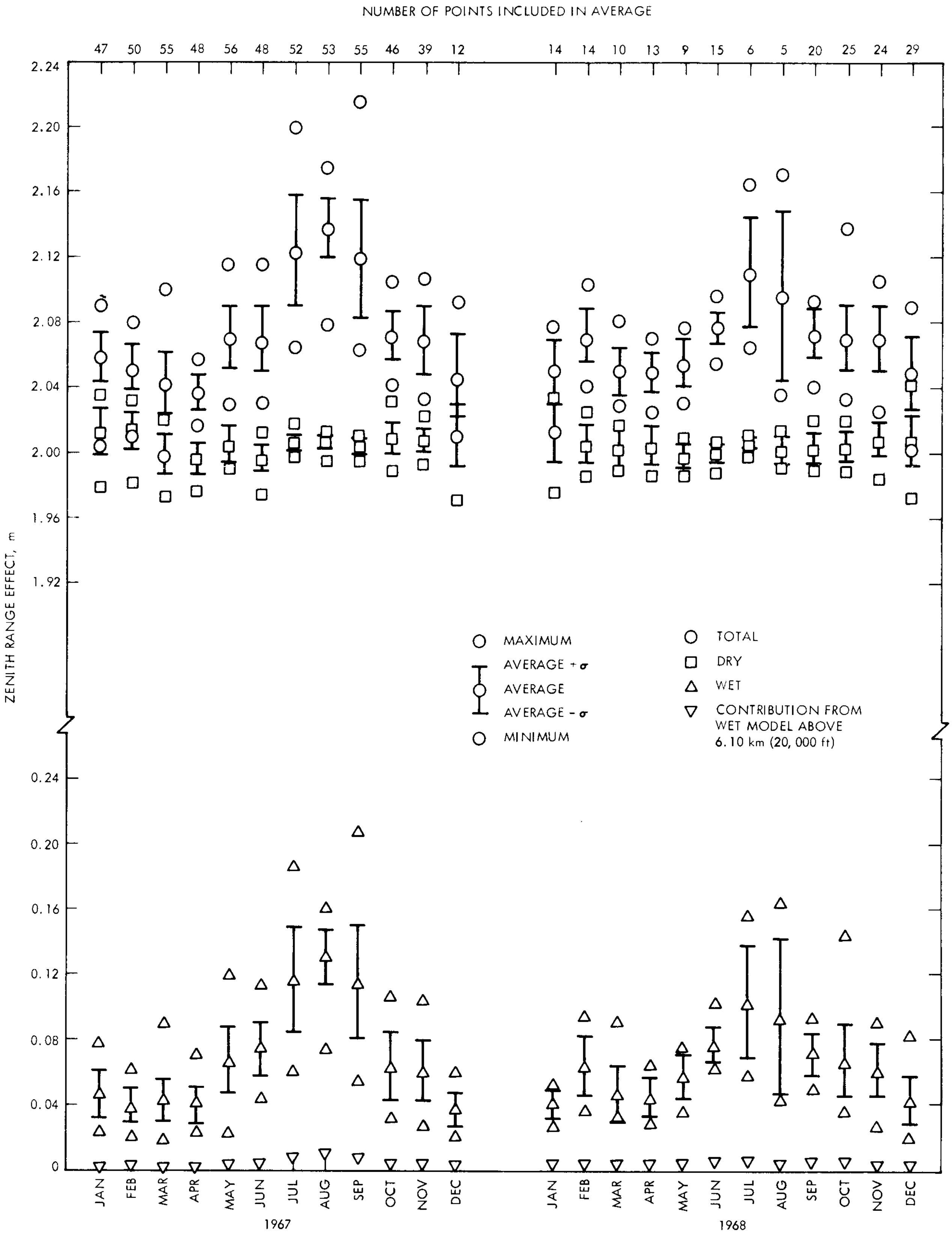


Fig. 2. Monthly averages and standard deviations of total, dry, and wet zenith range effects over Yucca Flats during 1967 and 1968

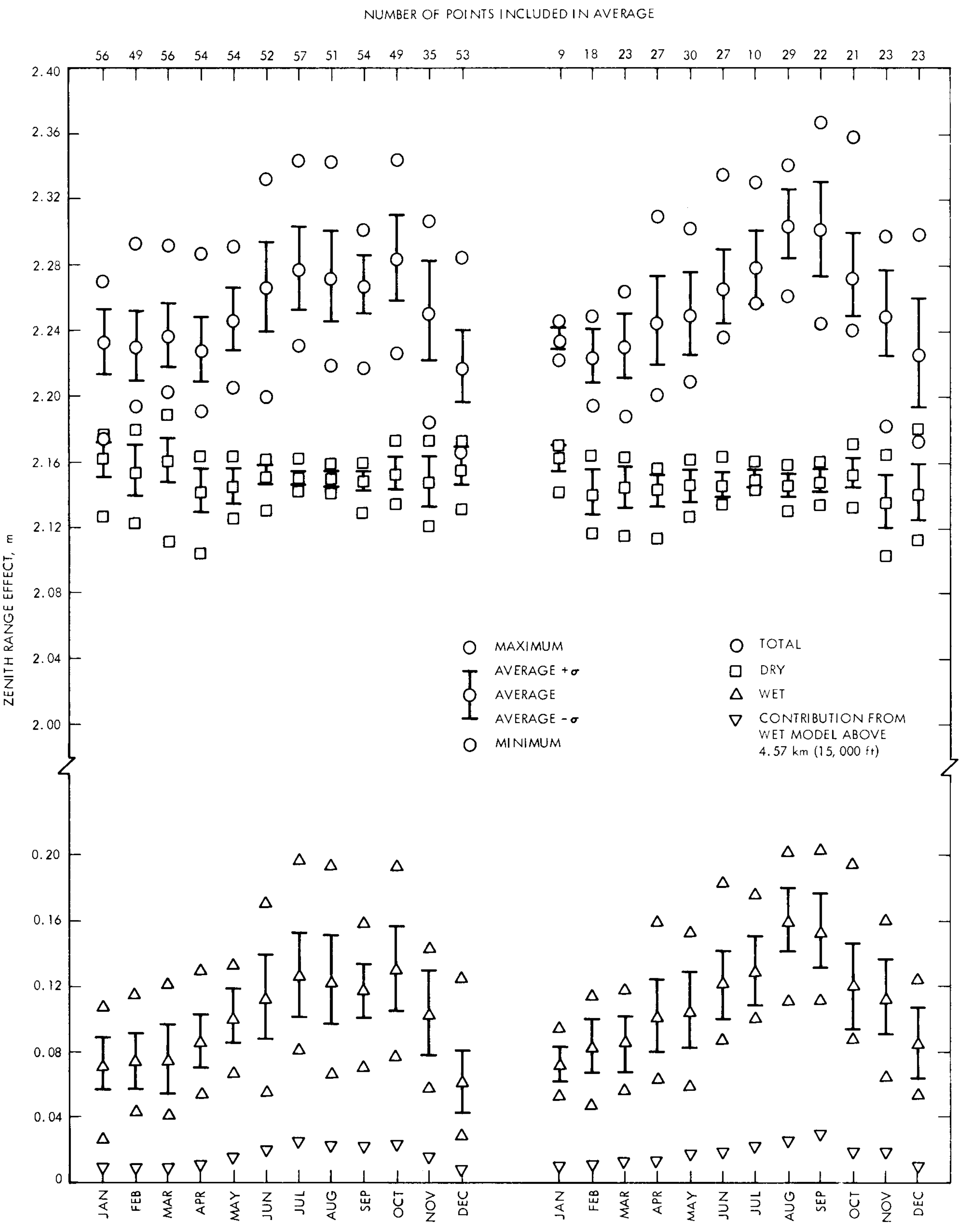


Fig. 3. Monthly averages and standard deviations of total, dry, and wet zenith range effects over Madrid during 1967 and 1968

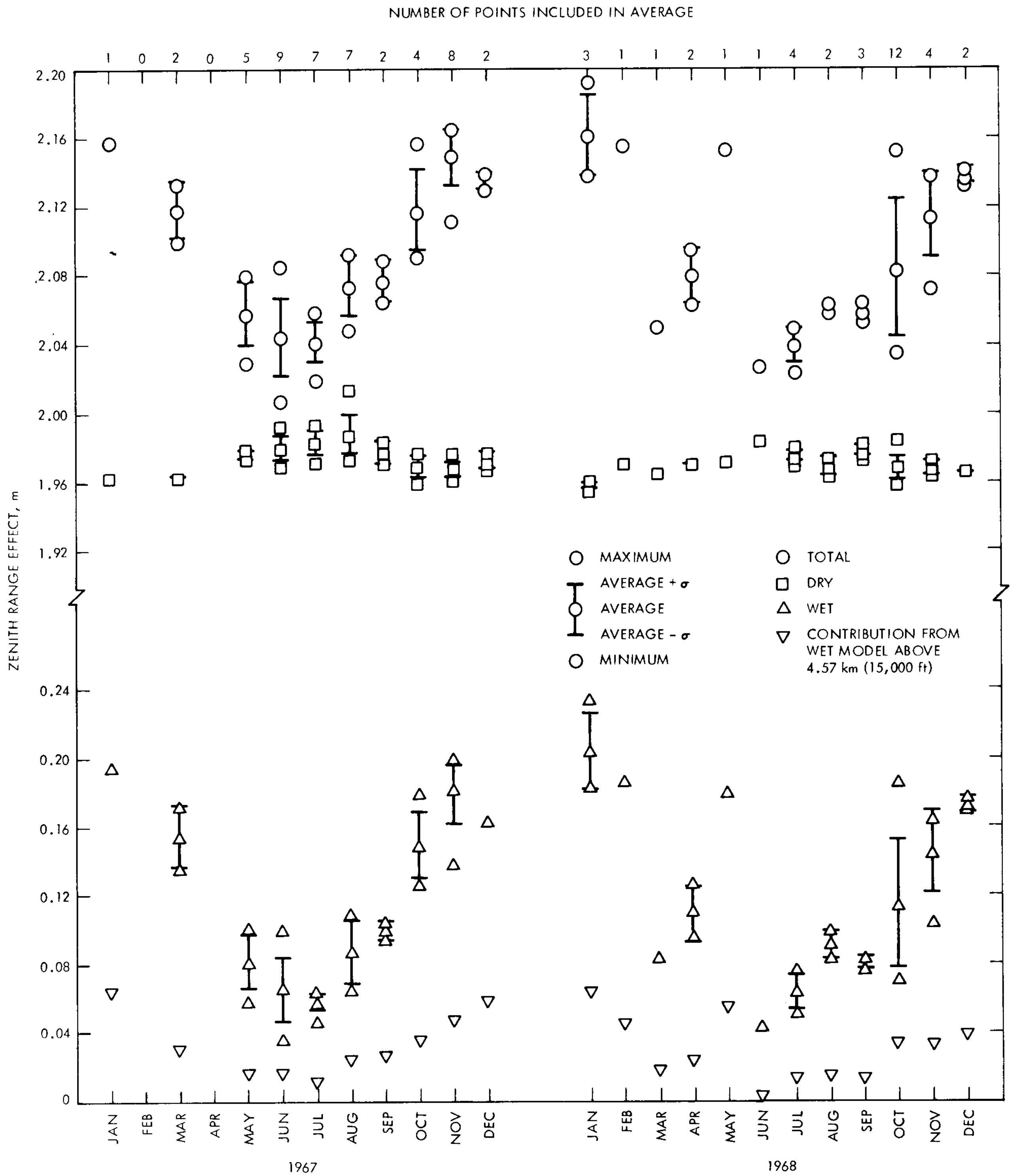


Fig. 4. Monthly averages and standard deviations of total, dry, and wet zenith range effects over Pretoria during 1967 and 1968

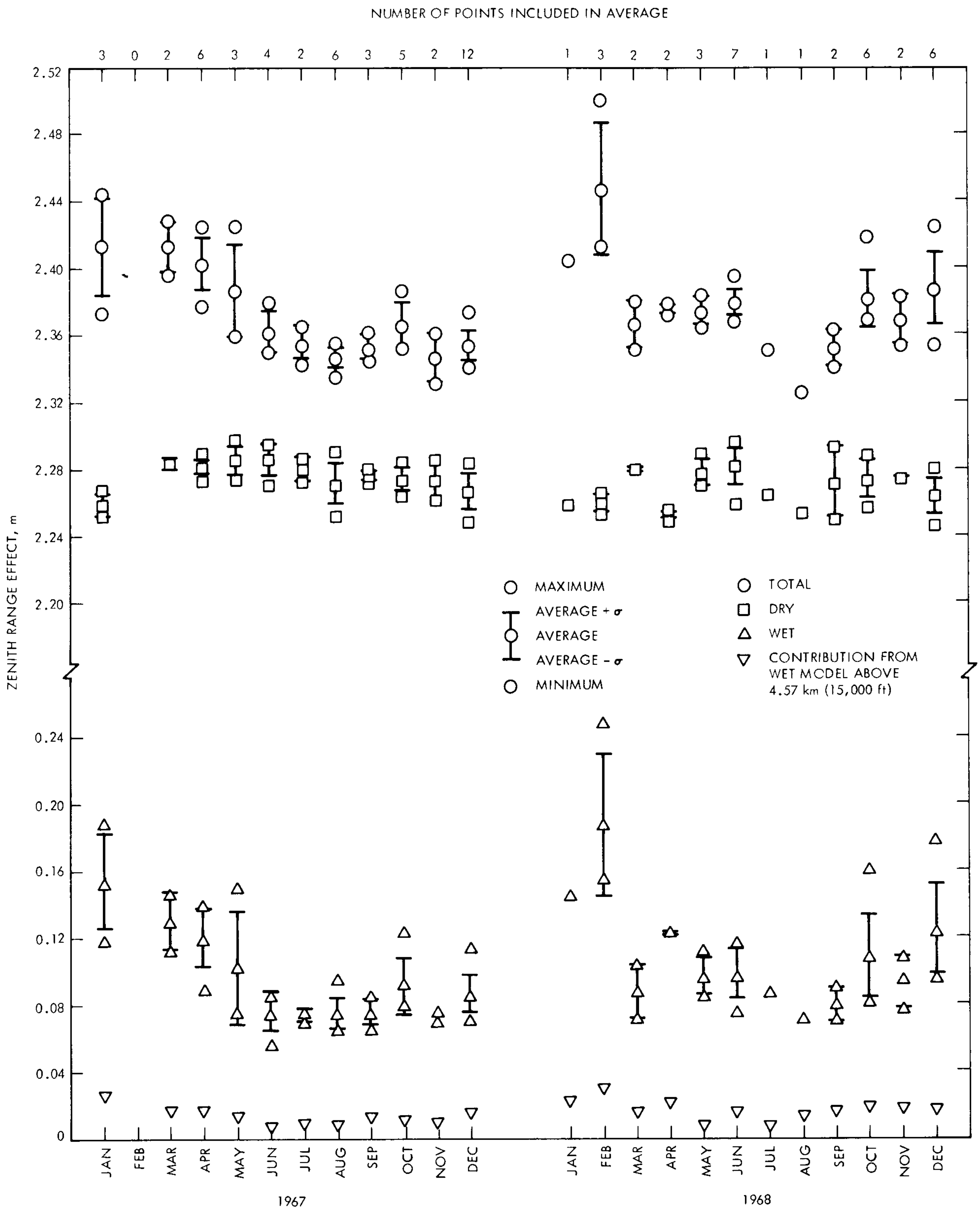


Fig. 5. Monthly averages and standard deviations of total, dry, and wet zenith range effects over Woomera during 1967 and 1968

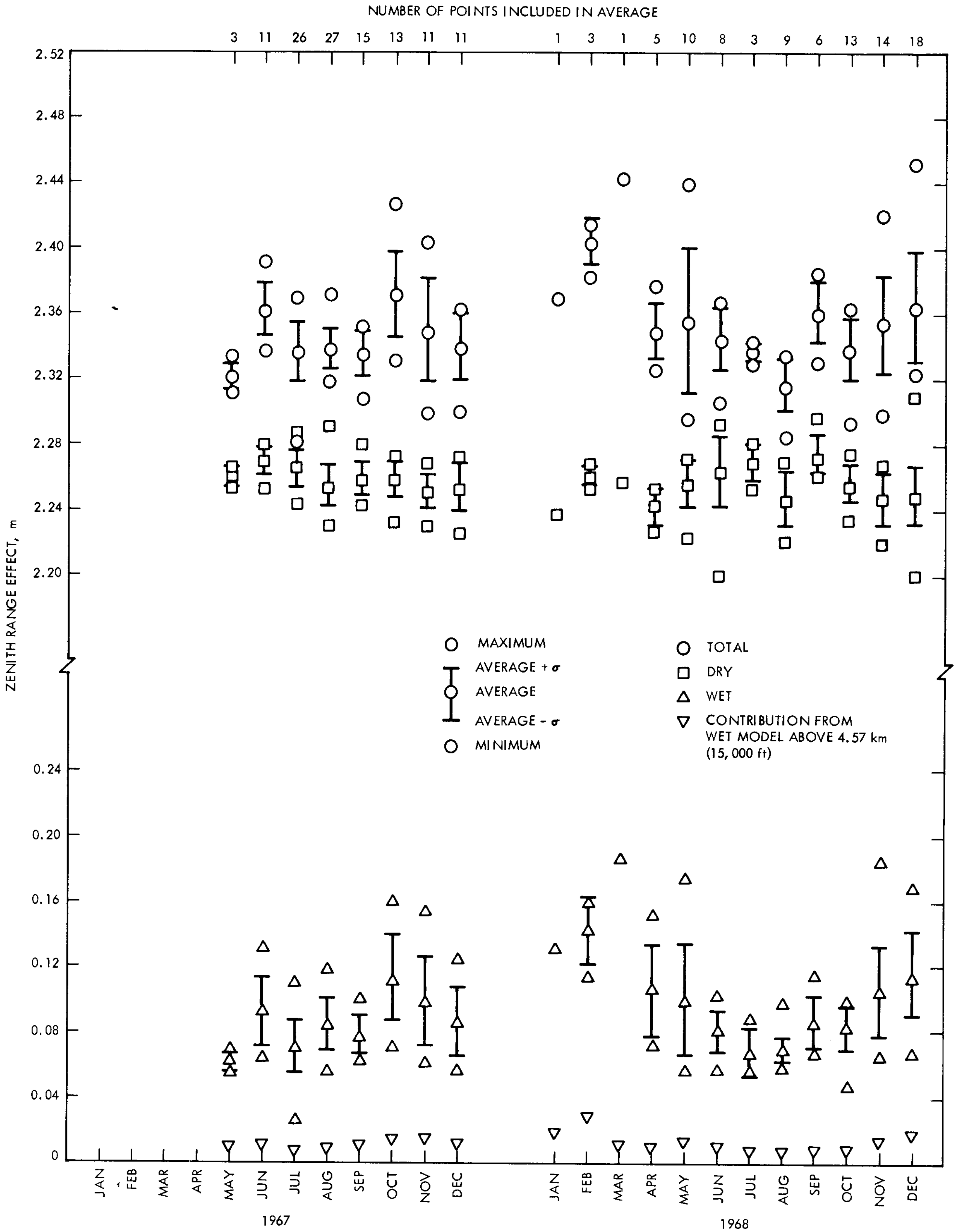


Fig. 6. Monthly averages and standard deviations of total, dry, and wet zenith range effects over Wagga during 1967 and 1968

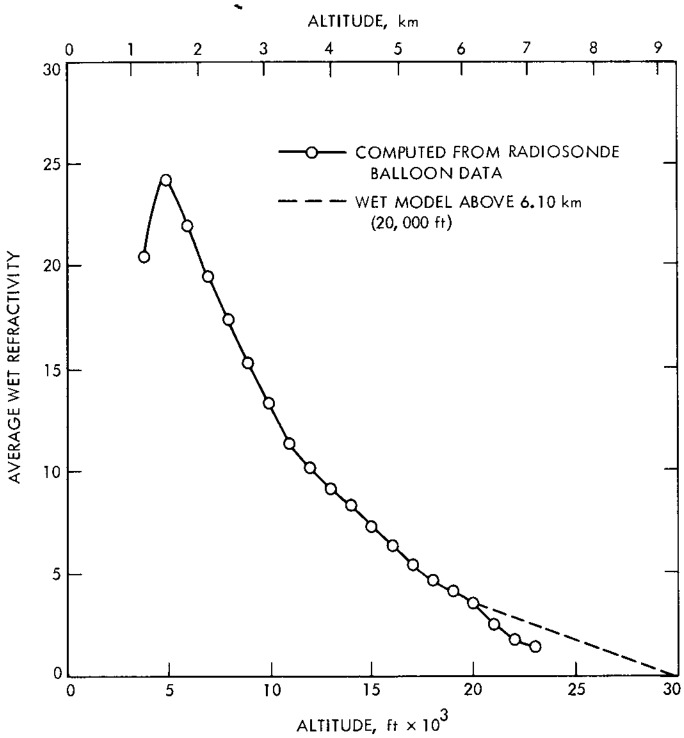


Fig. 7. Actual and modeled averaged wet refractivity above Yucca Flats during October 1968

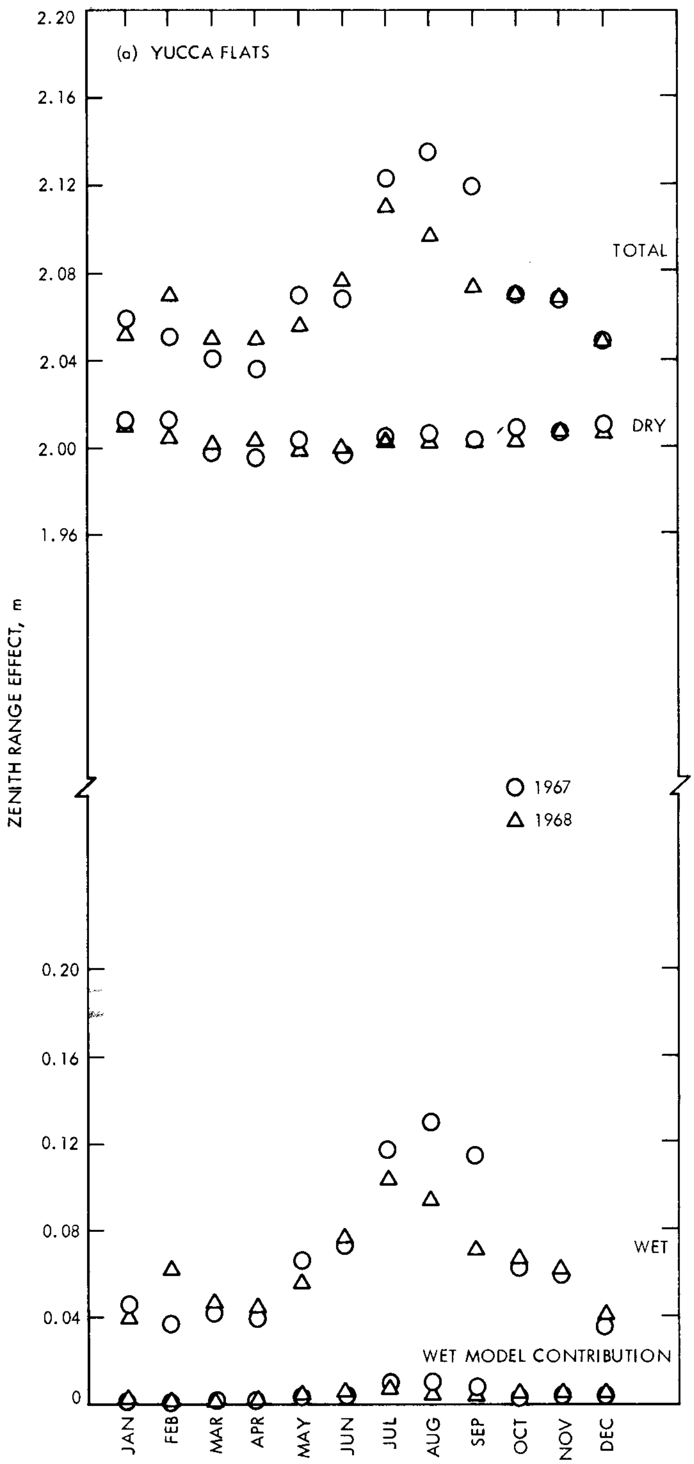
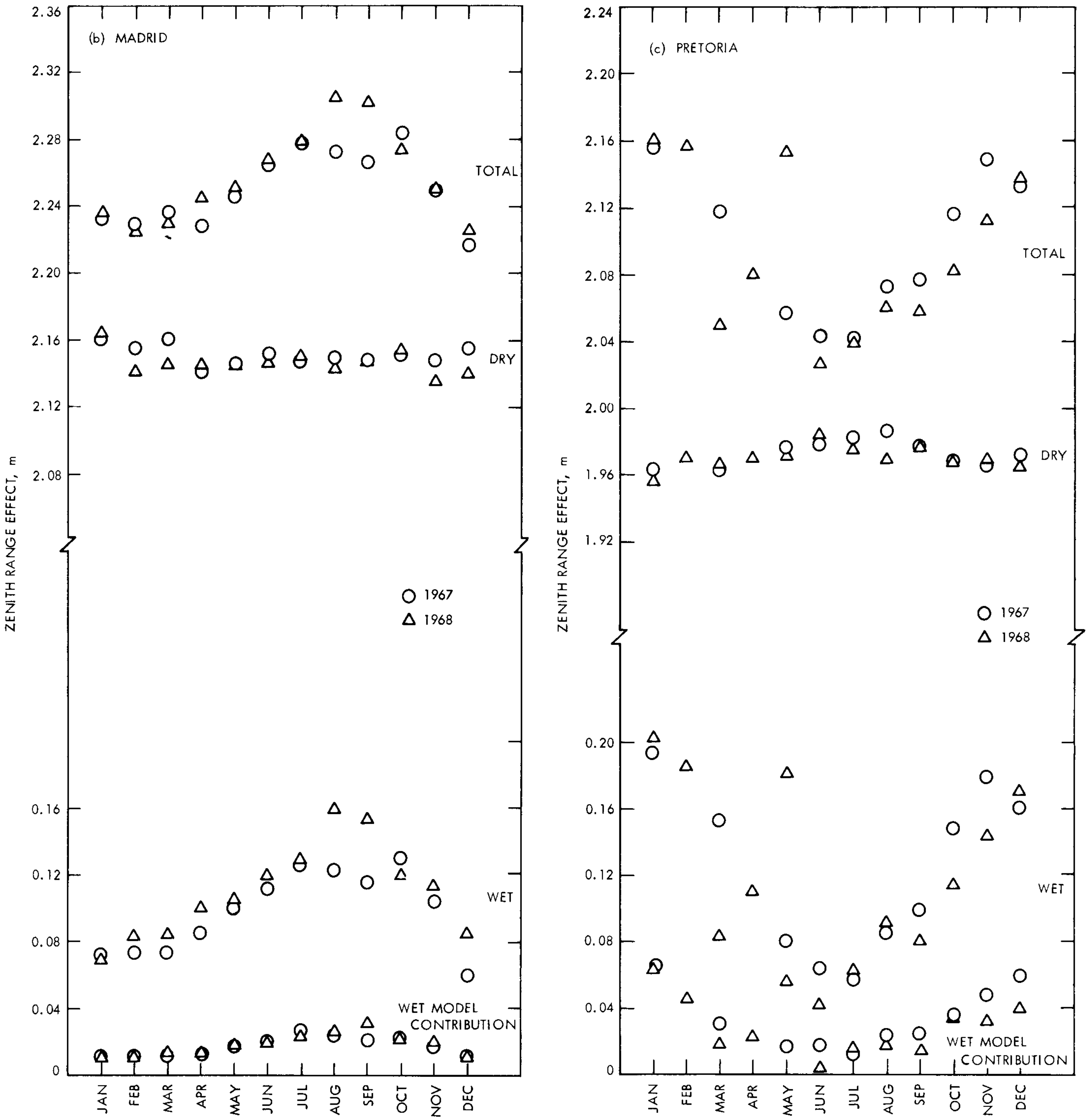
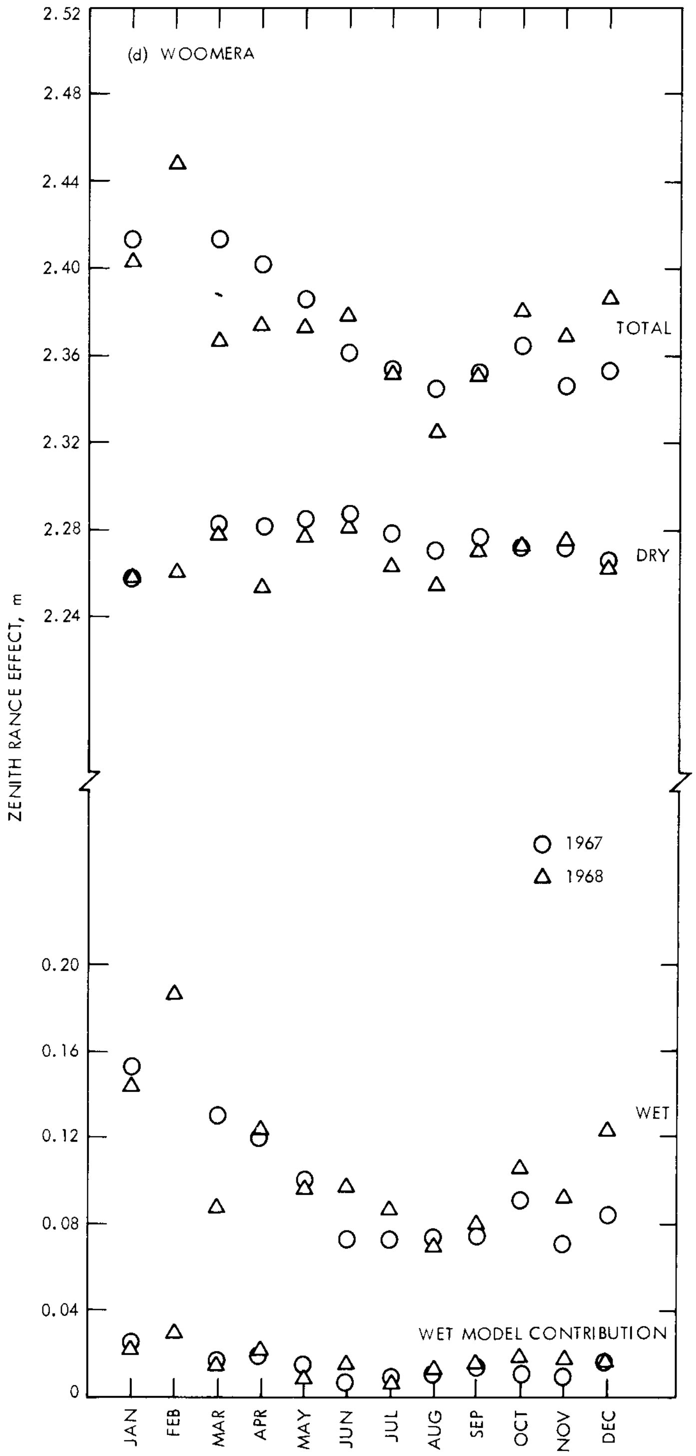


Fig. 8. Comparison of zenith range effect monthly averages over various sites



(b) MADRID
(c) PRETORIA
ZENITH RANGE EFFECT, m
TOTAL
DRY
WET
WET MODEL CONTRIBUTION
1967
1968
2.36
2.32
2.28
2.24
2.20
2.16
2.12
2.08
0.16
0.12
0.08
0.04
0
2.24
2.20
2.16
2.12
2.08
2.04
2.00
1.96
1.92
0.20
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

Fig. 8 (contd)


(d) WOOMERA
TOTAL
DRY
WET
WET MODEL CONTRIBUTION
ZENITH RANGE EFFECT, m
1967
1968
2.52
2.48
2.44
2.40
2.36
2.32
2.28
2.24
0.20
0.16
0.12
0.08
0.04
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

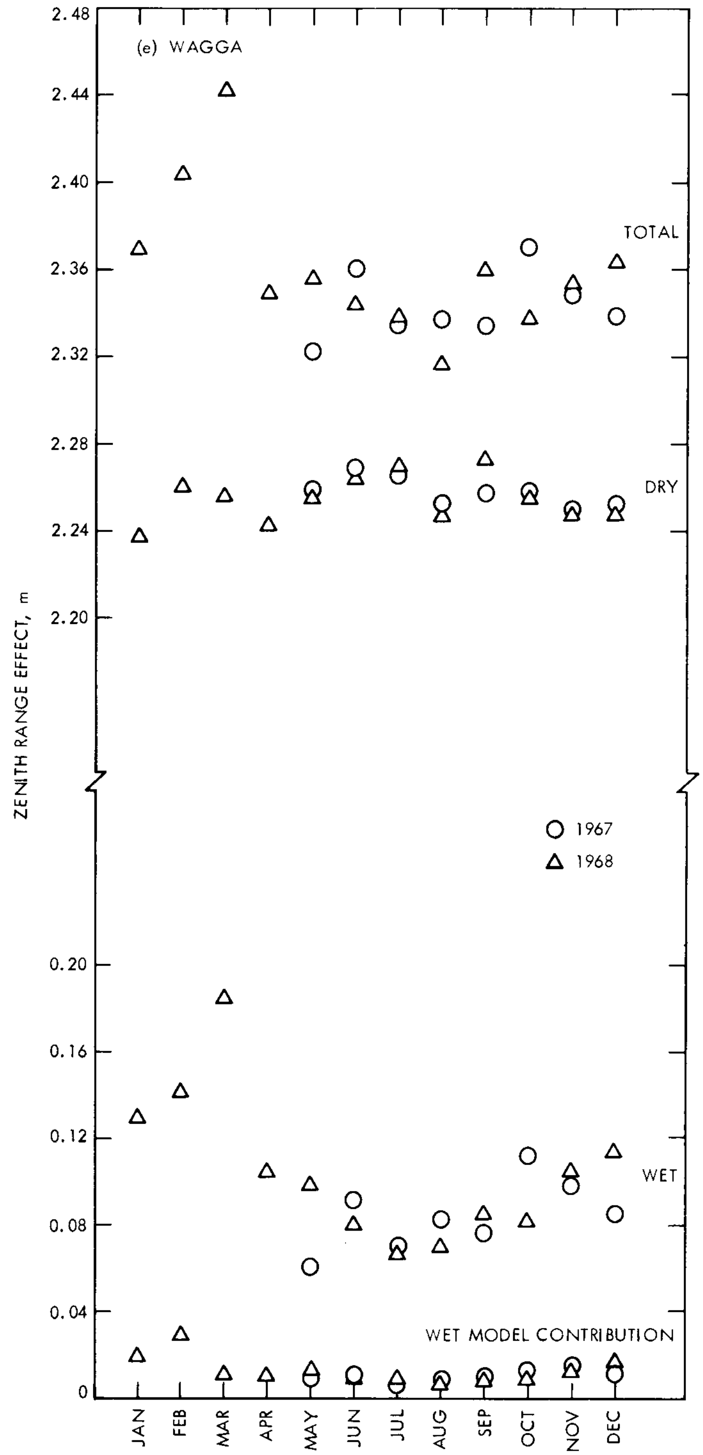

(e) WAGGA
TOTAL
DRY
WET
WET MODEL CONTRIBUTION
ZENITH RANGE EFFECT, m
1967
1968
2.48
2.44
2.40
2.36
2.32
2.28
2.24
2.20
0.20
0.16
0.12
0.08
0.04
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

Fig. 8 (contd)

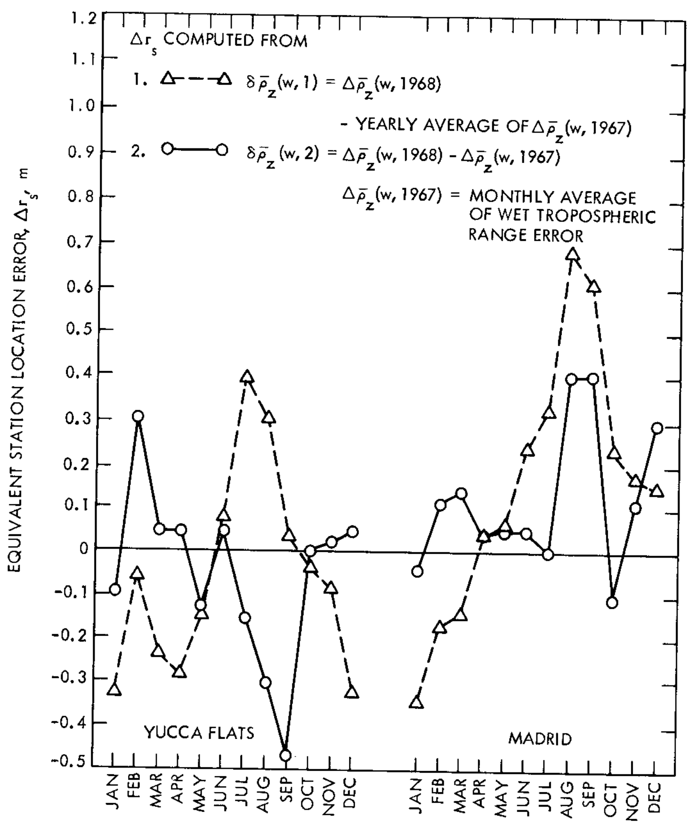


Fig. 9. Monthly averages of equivalent station location error produced by calibrating 1968 zero declination and 10-deg minimum elevation angle tracking data, using a wet troposphere model with 1967 parameters